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STORM OVER EXMOOR ON AUGUST 15, 1952

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The rainfall over Exmoor which caused the Lynmouth flood disaster of August 15, 1952, produced one of the three heaviest falls in 24 hr. which have ever been recorded in the British Isles. In a Meteorological Office rain-gauge set up as recently as August 27, 1951, near Longstone Barrow on the ridge running from west to east about five miles south of the coast, a voluntary observer, Mr. C. H. Archer of Wootton Courtenay, near Minehead, measured 9·00 in. for the 24 hr. beginning at 0900 G.M.T. on the 15th.

The Longstone Barrow fall and its place in the records.—To explain the authenticity of this reading it needs to be said that it was not strictly a 24-hr. measurement in the usual sense. A standard rain-gauge is read daily at 0900 G.M.T., a practice which gives rise to the definition of a "rainfall day" as the period of 24 hr. beginning at this time on the date specified. But the gauge near Longstone Barrow is in a very remote spot at an altitude of 1,550 ft. above mean sea level, and it could scarcely be visited every day even by one of the few inhabitants of the moorland neighbourhood. It is in fact a monthly gauge intended to be read only on the first day of each month. Fortunately the observer makes additional readings of this and other monthly gauges for which he is responsible, and had made one such observation at about 1500 G.M.T. on August 14. On the 16th, appreciating the significance of what had occurred, he made a very difficult journey through Simonsbath along roads made almost impassable by flood debris, and then across the moor on foot, to take another reading at about 1130 G.M.T. on that day. The total rainfall for the intervening $44\frac{1}{2}$ hr. was 9·04 in., and there is ample reason to suppose that 0·04 in. is a generous allowance for the meagre falls which must be credited to the rainfall days 14th and 16th. The reading of 9·00 in. for the 15th may therefore be accepted and considered as reliable as the usual daily observation at a rainfall station. It is probably accurate within one or two per cent. Two other measurements made with standard gauges for the 15th approached this fall in magnitude. They were 7·58 in. at Challacombe and 7·35 in. at Honeymead, near Simonsbath, both on lower ground within a few miles of Longstone Barrow. There was abundant supporting evidence as will appear.

A total of 9·00 in. in 24 hr. has been surpassed only twice in the records of the British Rainfall Organization, which now go back, with fair cover for most of the British Isles, over a period of 80 or 90 years. There was a fall of 9·56 in. on June 28, 1917, at Bruton and one of 9·40 in. on August 18, 1924, at Cannington, in each case for the rainfall day. It is rather odd that these two outstanding falls both occurred in Somerset, and that the third highest now added to the

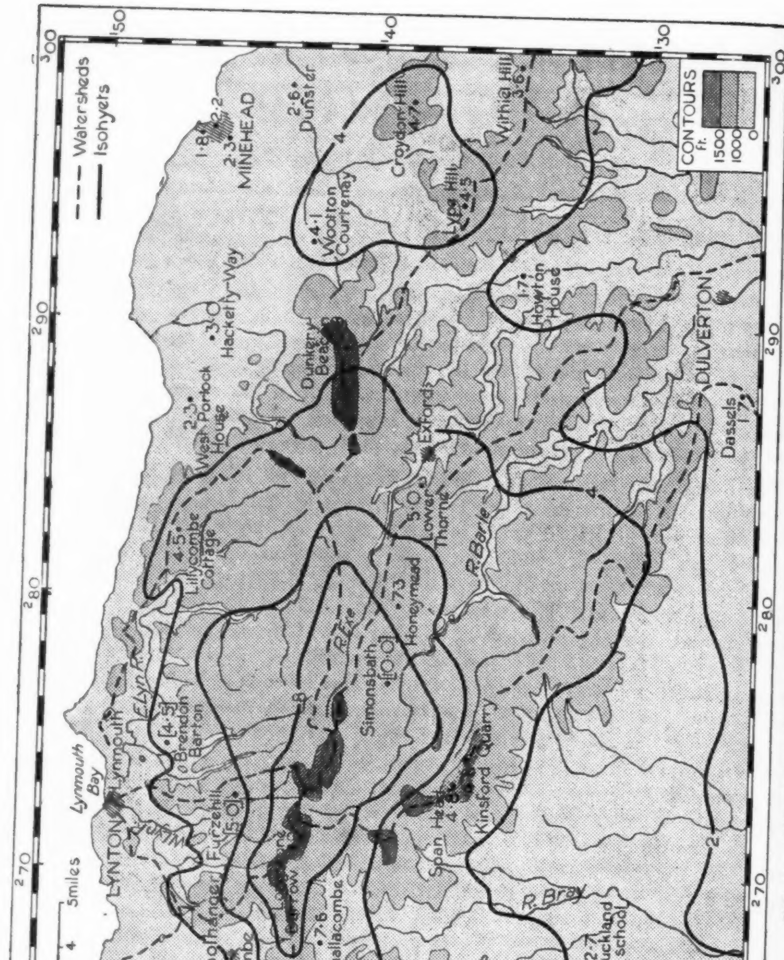


FIG. 1—RAINFALL DISTRIBUTION OVER EXMOOR, AUGUST 15, 1952

list was recorded in Devon at a point only about half a mile from the Somerset border. But the data so far available do not justify the conclusion that other parts of the country are relatively immune from such intense rains.

Investigation of the storm.—Within a few days of the storm special efforts were made to collect all the routine rainfall data from the district, with any additional information which the observers were able to give, so that a provisional assessment could be available at once. At the same time Mr. Archer began a thorough exploration, sponsored by the Meteorological Office, of all the headstreams draining down from the area which received the most intense rain. His own investigations continued for very nearly two months including a period during the first month when he conducted Mr. Bleasdale round many of the most impressive scenes on the moor and photographs were taken. Contact was made with other investigators, and photographs and other information were requested from the public. The large amount of data which has thus been collected is still increasing, but the main features of the storm are already clear and are summarized below.

Distribution of the rainfall in space.—The distribution of rainfall for the rainfall day of August 15 is shown in broad outline on the map of the Exmoor district shown in Fig. 1. Values plotted to the nearest tenth of an inch are for the most part from recognized rainfall stations. Three exceptional values are inserted in square brackets; these are approximate readings obtained by unorthodox methods. That at Brendon Barton came from a well exposed camp site where chance catches were made in an almost cylindrical pressure cooker and in an ordinary bucket. The actual rainfall may have been a little more than 5 in. and the value plotted is a cautious estimate. An amount corresponding to about 4 in. of rain was caught in an old and worn bucket in a seriously over-sheltered site at Furzehill; it seems unlikely that the true fall there was greater than 5 in. The most interesting of the three estimates was due to the fortunate circumstance that at 1845 G.M.T. on the 15th an accurately cylindrical bucket graduated in quarts, and in excellent condition, was left out in the middle of a field at Simonsbath. The general exposure was very good and the conditions required of a standard rain-gauge were almost observed except that the bucket did not have a sharp rim and that there must have been some loss from splashing when the water rose towards the top. Careful measurement and calculation showed that the catch observed the next morning was equivalent to 9·1 in. of rain. From relevant reports it seems hardly possible that less than 1 in. of rain fell at Simonsbath before 1845 G.M.T. and the value plotted on the map is very cautious. The true fall for the day may have been as much as 11 or even nearly 12 in., though it may also be true that such a large fall was very local. The possibility of using certain reservoir data as a further check on the heaviest falls is being pursued.

Isohyets are drawn on the map at intervals of 2 in. It would be unreasonable to attempt much greater detail, and the lines as they stand are rather generalized. There was evidence on the moor of seeming variations from place to place in the intensity and total amount of rainfall, but owing to the complexity of the country in soil and vegetation cover, in the nature of the underlying strata, and above all perhaps in the gradients encountered near the headstreams, it would be difficult if not impossible to carry through a valid analysis of all the variations suspected. The most notable example was a small area about

three-quarters of a mile north of the gauge at Span Head which appeared to have received a heavier fall than the 6 in. suggested by the map, unless perhaps the intensity of the rain was at that point very high for a relatively short time. It is also probable that some parts of the coastal ridge running east-south-east from Lynmouth Bay received more than 4 in. where the map indicates rather less. The isohyets were originally drawn on the basis of standard rain-gauge readings alone, and information supplied at an early date to certain official bodies was derived in part from this provisional map. It has now been slightly modified to take account of the value for Lillycombe Cottage near Culbone which was received late, of the estimates for Furzehill and Brendon Barton, and of the results of the investigations in the central district, which roughly coincides with the area enclosed by the 8-in. isohyet, and includes the estimate of 10 in. or more for Simonsbath. If the attempt were made to add a 9-in. isohyet it would be advisable to limit this to two separate small areas east or east-south-east from Longstone Barrow and north-west from Simonsbath with a very small area enclosed by a 10-in. isohyet within the latter. The modifications have not greatly changed the original estimates of the general rainfall over the drainage areas of the West Lyn and East Lyn rivers, which are of importance in connexion with the Lynmouth flood. They show an increase on any previous estimates which could have been made for the areas draining down the Exe valley to Exford and down the Barle and its tributaries to Simonsbath and subsequently to Dulverton. The investigations have shown, at least in part, the cause of the sudden high flood at Exford, which might not at first have been apparent from the rainfall readings alone except by a very bold extrapolation from the reading at Honeymead.

TABLE I—GENERAL RAINFALL AND TOTAL VOLUME OR WEIGHT OF WATER RECEIVED IN VARIOUS DRAINAGE AREAS

Drainage area	Area		General rainfall	Volume or weight of water received		
	sq. miles	acres	in.	cu. ft. $\times 10^6$	gallons $\times 10^6$	tons $\times 10^6$
West Lyn	9·1	5,800	5·87	124	773	3·45
East Lyn	30·1	19,300	5·56	389	2,422	10·81
Combined area above Lynmouth	39·2	25,100	5·63	513	3,195	14·26
Exe above Exford	7·3	4,650	6·71	114	709	3·16
Barle above Simonsbath	8·2	5,200	8·00	152	949	4·24
Heddon down to sea	12·2	7,800	4·27	121	754	3·37
Heddon above Parracombe	2·3	1,500	6·49	35	216	0·96

Revised estimates of the general rainfall over certain drainage areas and of the volume of water to which these estimates correspond are set out in Table I. The number of significant figures given for these values goes beyond the attainable accuracy which, for general rainfall and dependent calculations, may be taken as about $\pm$ 5 per cent., or at the very worst $\pm$ 10 per cent. Approximate estimates of the total areas which received falls above given limits are:—

	sq. miles
more than 8 in.	17·0
more than 6 in.	42·5
more than 4 in.	
(i) main area	140·0
(ii) small area to the east	13·3

Over the area represented by the map (Fig. 1) the general rainfall was about 3·7 in., equivalent to an amount of water falling over this tract of country of the order of 90 million tons.

One feature of the distribution which is worthy of note is that it appears to consist of a pattern determined largely by orographical influences upon which are superimposed irregularities due to the thundery characteristics of the storm. The separate enclosed area to the east which received more than 4 in. may have been due to an additional thundery shower which occurred in the early hours of the 16th and appeared prominently on the chart of the recording rain-gauge at Wootton Courtenay, but probably did not occur over most parts of Exmoor. In conformity with the mainly orographical pattern an area on the northern side of Dartmoor, perhaps 50 sq. miles in extent, also received more than 4 in., and high ground in south Wales received amounts ranging up to 3 in. Another irregularity occurred in the Torridge valley about 10 miles south of Barnstaple and 15 miles south-west of the centre of the Exmoor storm, where a relatively low-lying area round Torrington received more than 4 in.

Distribution of the rainfall in time.—Unfortunately there are no recording rain-gauges in the heart of Exmoor. The two nearest are at Chivenor, about 14 miles west-south-west of Longstone Barrow, and at Wootton Courtenay, the same distance east. The two records have been carefully analysed using intervals of 6 min. along the time-scale, and the results are shown diagrammatically in Fig. 2. Each 6-min. fall is represented as a rate of rainfall in inches per hour. It cannot be confidently stated that the accuracy aimed at in this fine-scale analysis, indicated by the method of drawing the diagram, has actually been achieved, but an independent check produced very similar results. The totals obtained from the data shown differ by less than 8 per cent. from the accepted 24-hr. falls recorded by standard gauges at the two stations, and there is little doubt that the diagram is substantially correct.

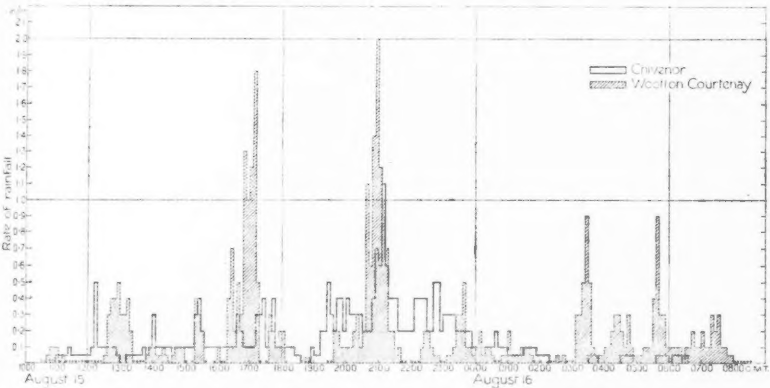


FIG. 2—RATES OF RAINFALL, CHIVENOR AND WOOTTON COURTENAY, AUGUST 15–16, 1952

Despite the distance between the two stations there is a degree of agreement, particularly in the timing of the most intense fall of the day, where the difference is a matter of a few minutes, and in the quieter period which preceded it. It

does not immediately follow that the same timing is valid for the whole of Exmoor, and in fact there is some evidence against this, but the agreement provides a basis for the interpretation of eye-witness accounts which are not entirely in harmony even where there is reason to expect that they should be. An analysis of the data in hourly periods centred on the full hour and adjusted to give agreement with the standard-gauge reading is set out in Table II. Eliminating the heavy fall in the early morning of the 16th at Wootton Courtenay, which, it has been suggested, corresponds with the small enclosed 4-in. isohyet on the rainfall map, the amounts for the two stations up to 0230 G.M.T. are 2·61 in. at Chivenor and 3·03 in. at Wootton Courtenay. Of these amounts the falls during the 7 hr. beginning at 1630 G.M.T. were 1·77 in. and 2·05 in. respectively, very nearly 68 per cent. at each station. It is in this 7-hr. period that the main interest of the storm over Exmoor is concentrated, and the general pattern of the rainfall day may be considered to be: rain starting before midday and continuing throughout the afternoon, becoming heavy at times and building up to a downpour in the late afternoon or early evening, then a brief respite followed by a torrential downpour lasting for three or four hours up to about midnight during which very roughly half the total for the rainfall day came down, thereafter gradually ceasing during the early hours except for minor sporadic outbursts.

TABLE II—HOURLY RAINFALL AT CHIVENOR AND WOOTTON COURTENAY, AUGUST 15–16, 1952

	Chivenor	Wootton Courtenay		Chivenor	Wootton Courtenay		Chivenor	Wootton Courtenay
G.M.T.	in.	in.	G.M.T.	in.	in.	G.M.T.	in.	in.
0930–1030	0·00	0·00	1830–1930	0·11	0·01	0330–0430	0·01	0·19
1030–1130	0·03	0·05	1930–2030	0·30	0·13	0430–0530	0·02	0·13
1130–1230	0·11	0·02	2030–2130	0·46	0·92	0530–0630	0·03	0·27
1230–1330	0·07	0·31	2130–2230	0·29	0·05	0630–0730	trace	0·16
1330–1430	0·10	0·05	2230–2330	0·29	0·10	0730–0830	0·00	0·07
1430–1530	0·14	0·12	2330–0030	0·14	0·17	0830–0930	0·00	trace
1530–1630	0·11	0·16	0030–0130	0·08	0·06	0930–1030	0·00	0·00
1630–1730	0·19	0·73	0130–0230	0·06	0·04			
1730–1830	0·13	0·11	0230–0330	0·00	0·23	Standard gauge*	2·67	4·08

* 0900 G.M.T. 15th to 0900 G.M.T. 16th.

The combined evidence of more than a dozen eye-witnesses who were in various parts of Exmoor during the storm is very confused, and there is as much disagreement within some groups of reports from neighbouring localities as there is between those from widely separated points. It is of course very understandable that this should be so. Most of the witnesses were extremely busy for a good part of the time because of the effects of the storm and flood; largely as a result of this there were instances of a failure to distinguish clearly between rain precipitated in the immediate neighbourhood and the torrents rushing downstream or downhill, in many places through previously dry or non-existent channels. Several witnesses said that the torrential rain was uniformly heavy for a number of hours, an observation which is most unlikely to have been valid. A few failed to remember any distinct easing of the fall in the early evening, and of the majority who spoke of two heavy falls some thought that the earlier was the heavier. There was no clear statement that there were more than two exceptionally heavy falls. Two independent reports of thunder and lightning were in disagreement, one stating definitely that it

was severest just before the torrential evening fall and the other that it occurred mainly during this period. Though these witnesses were separated by only 2 miles it is just possible that both reports are valid; of the two the former is probably the more reliable. There was no report of hail.

In the circumstances it is best to take all the accounts together and form a composite picture of the storm as a whole with two qualifications: (i) that the heaviest rain may have occurred somewhat earlier toward the north and north-east, and a little later toward the south and south-west (the accounts suggest this but are not sufficiently accurate for any such difference to be determined with precision); and (ii) that the relationship of the two heaviest bursts may perhaps have been inverted near the coastal ridge east of Lynmouth. The description which then emerges is in substantial agreement with the combined pattern from the recording rain-gauges at Chivenor and Wootton Courtenay. Rain started at some time during the morning, probably towards 1100 or 1200 G.M.T. in many places. It was heavy at times during the afternoon with brighter intervals locally, and the first exceptionally heavy downpour occurred, after unusual darkening of the sky and peculiar colour effects, between 1530 and 1730 G.M.T., thereafter easing. Torrential rain occurred between 1830 and 2230 G.M.T., accounts of the precise timing differing slightly and very erratically from place to place; it slowly eased off with little rain of importance in most places after about 0200 G.M.T. on the 16th, though there were some reports of rain or showers throughout the night and until well into the next morning. There is little doubt that over most of Exmoor the phenomenal rain during the main evening fall was more prolonged than the Wootton-Courtenay record suggests, and was very much heavier than the first burst. It is therefore necessary to give more weight to the Chivenor record, though with a shift of the rainfall pattern in time to about one hour earlier. On such a basis Table III may be taken as giving an approximation to the percentage distribution of rainfall in time for Exmoor as a whole.

TABLE III—DISTRIBUTION IN TIME OF RAINFALL OVER EXMOOR, AUGUST 15–16, 1952

Time	Rainfall	Time	Rainfall
G.M.T.	per cent.	G.M.T.	per cent.
0900–1530	15	1930–2030	18
		2030–2130	18
1530–1630	8	2130–2230	10
1630–1730	8		
1730–1830	3	2230–0900	10
1830–1930	10		

In using this distribution the two qualifications mentioned above must be taken into account, and the possibility of certain other modifications must be considered: (i) on the eastern flank of Exmoor in particular a greater percentage should be allotted to the final period after 2230 G.M.T.; (ii) the distribution as it stands may apply fairly accurately to most places elsewhere which received about 5 in., though a possible shift in time should be allowed for; (iii) in places which received much less than 5 in. there should probably be a decrease in the percentages for the heaviest fall, to correspond more closely with the Chivenor record, and *vice versa;* and (iv) for areas of a few square miles upwards a smoothing of the percentages to take account of local variations in timing is probably desirable. Some accounts of the flooding

show that in places it occurred with extraordinary suddenness, but it is unnecessary to suppose that the heaviest fall began with a sudden burst, even locally, as no direct evidence for this was found, and satisfactory alternative explanations of the flooding can be advanced. With the adjustments suggested it will probably be safe to apply this distribution in time to the general rainfall for the drainage areas listed in Table I, though for individual localities the need for caution is shown by the report from Lower Thorne near Exford. Out of a 24-hr. total of 4·96 in. separate measurements gave 2·37 in. from 1815 to 2020 G.M.T., and 0·77 in. from 2020 to 2040 G.M.T.

Synoptic situation.—The outbreak of thunderstorms and phenomenal rainfall was the culmination of a four-month period in which there was a high incidence of heavy thunderstorms, especially in south-western districts and the west Midlands, with notably severe thunderstorms on April 16, May 19, June 13, and July 1 and 6. Though the regions affected are liable to heavy storms, it must be unusual to have six in one year. Naturally their worst incidence was not exactly in the same region, but Exmoor was badly affected on April 16.

The small depression responsible for the great rainstorm was first clearly shown over the Atlantic at 1200 G.M.T. on August 12, centred at about 47°N., 34°W. with central pressure about 1016 mb. It first moved east-south-east to a position near 43°N., 19°W. at 0000 on the 14th when its central pressure was 1007 mb. After that time it rounded an upper trough and then moved slowly north-east parallel to the general thermal gradient and the 500-mb. contours, not very far from the thermal trough. The track on 15th–16th is shown on Fig. 3; between 1500 and 1800 the centre moved north to near Exeter, and very soon afterwards it became occluded and subsequently drifted east-north-east as a dying system. No fronts were identified in its earlier stages, and the warm front shown on Fig. 3 (the 1500 G.M.T. chart on the 15th) was originally quite separate from the depression. It can probably be identified with the old Cold front marked H on the *Daily Weather Reports* for August 10–13, and as a quasi-stationary front over France and north-west Spain on the morning of the 14th. As the new depression approached, a small low developed over south-west France, and a warm front (largely superficial) moved north-west from France to southern England, entering the depression in the western English Channel. The origin of the cold front is not known; it was comparatively weak and it made a large angle with the mean thermal gradient up to both 700 and 500 mb., but the upper winds backed as it swept round the depression and finally occluded the warm sector.

A ship in the Bay of Biscay at 47½°N., 8°W. reported continuous drizzle at 1800 on the 14th, and by 2100 there was continuous slight rain at Scilly. The rain spread north-eastward, but the thundery outbreak which led up to the exceptionally heavy rainfall appears to have started in and near Brittany and crossed the English Channel. The sources of atmospherics were so far apart—there was an isolated "sferic" location in the Bay of Biscay on the 14th and only some scattered ones in France—that no important source could have escaped location. There was thunder during the evening at Brest, and also at Rennes at 2100 near the warm front. At 0430 on the 15th there was a group of "sferics" south of Plymouth and a few near the Brittany coast. The 700-mb. wind at Brest at 0300 was SSE., which favoured the movement of thunderstorms across the English Channel. Earlier in the night there was

some thunder in the Bristol-Channel area, but the main outbreak reached Plymouth shortly before 0700 and moved slowly northwards, and by 1500 (Fig. 3) it was mostly confined to north Devon and the Bristol-Channel area. To the west of the belt of heavy thundery rain there was a fairly large area of non-thundery rain, and to the east of it there were many more or less separate thunderstorms, in some cases severe but of a normal type. Over most of Cornwall and Devon the rain lasted all day and well into the night, and by midnight it had spread across Wales and the west Midlands.

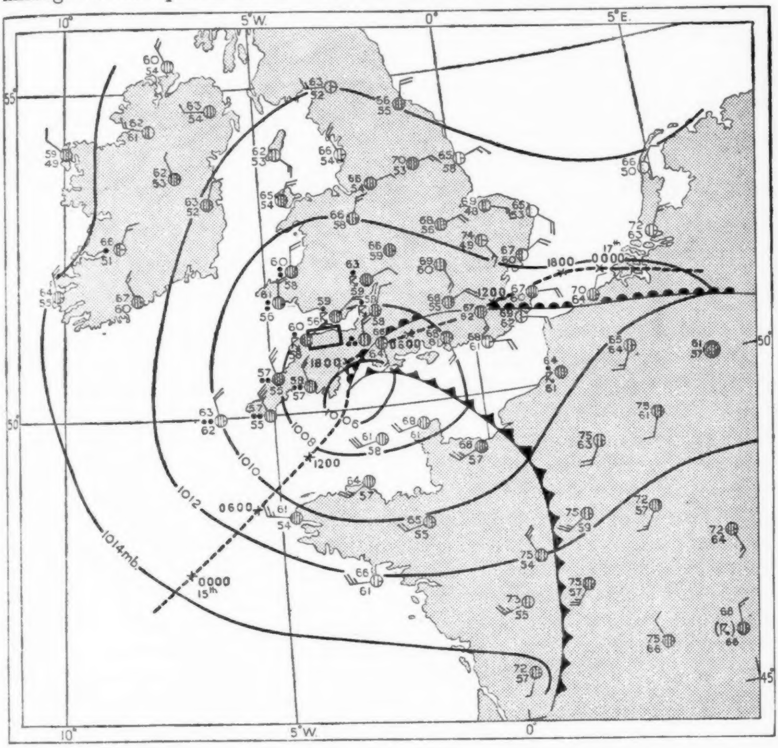


FIG. 3—SYNOPTIC CHART, 1500 G.M.T., AUGUST 15, 1952
The area covered by Fig. 1 is indicated by the small rectangle. The dew points are plotted below the temperature

Fig. 4 shows the 1400 G.M.T. soundings at Larkhill and Camborne. The amount of instability was much less than in many depressions which do not give exceptional rainfall. Table IV gives the upper-wind soundings in the area during the day. The two parts of the table may be compared from the following rough equivalents: 700 mb., 10,000 ft.; 500 mb., 18,000 ft.; 300 mb., 30,000 ft.

Any estimate of wind structure over the area of heaviest rainfall is necessarily rather speculative. The 700-mb. trough was quite close to that area in the evening, but probably just west of the rainfall maximum. There was a north-easterly geostrophic wind of 20 kt. in the Exmoor region during the evening,

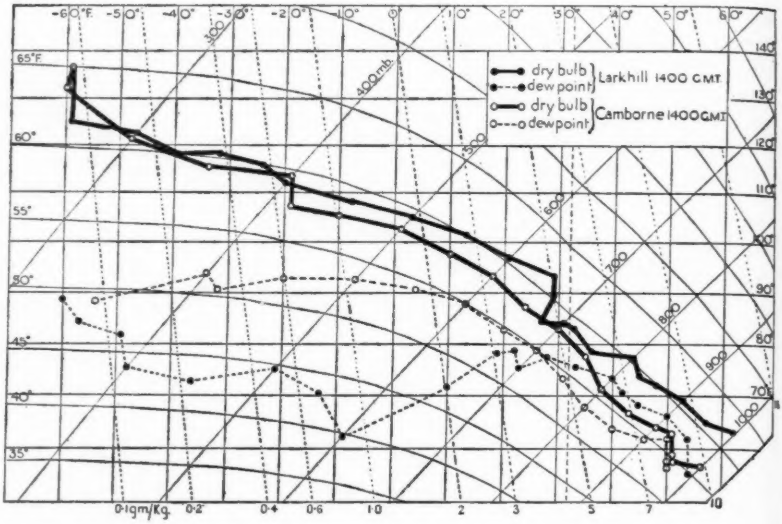


FIG. 4—PRESSURE AND TEMPERATURE SOUNDINGS, AUGUST 15, 1952

and it is fairly certain the wind veered with height, and was in the south-east quadrant in a fairly thick layer from 3,000 or 4,000 ft. up to 10,000 ft. or a little higher. This would allow the rain area to be fed from the warm sector air which held the most moisture. At 1500 (Fig. 3) the warm front was north-west of Henstridge (ten miles east of Yeovil) and about 50 miles from Longstone Barrow. At 1800 the distance from the front was probably 40 miles or even less. There was a difference of 160° in wind direction in the 25 miles between Henstridge and Merryfield (ten miles east-south-east of Taunton). The dew point was 64°F. at Henstridge and 65°F. at Hurn (near Bournemouth) at 1500, so that the surface reading on the Larkhill sounding was not representative of much of the warm-sector air. Probably the front had not quite reached Larkhill at 1400. The sustained heavy rain in Devon showed that ascent was taking place on a colossal scale, even over the low ground, and this ascending current could only have been supplied from the warm sector. The very damp

TABLE IV—UPPER WINDS ON AUGUST 15, 1952

	Brest 0300 G.M.T.		Larkhill 0300 G.M.T.		Larkhill 1400 G.M.T.		Camborne 1400 G.M.T.			Larkhill 0800 G.M.T.		Camborne 0800 G.M.T.		Larkhill 2000 G.M.T.	
mb.	°true	kt.	°true	kt.	°true	kt.	°true	kt.	ft.	°true	kt.	°true	kt.	°true	kt.
300	220	50	222	40	189	16	187	21	30,000	220	36	180	32	100	16
400	...	...	214	28	186	17	185	15	24,000	210	23	180	17	140	14
500	230	30	232	25	183	20	227	4	18,000	210	12	210	5	180	14
600	...	...	223	26	183	20	254	10	14,000	200	14	120	7	190	19
700	160	19	215	13	157	24	284	6	10,000	180	11	90	8	160	13
750	...	...	182	7	146	23	333	7	8,000	160	9	70	13	140	13
800	...	...	140	7	141	18	351	9	6,000	120	7	70	14	130	14
850	...	...	125	10	130	15	352	14	4,000	100	12	50	15	140	14
900	...	...	114	8	119	15	342	22	2,000	90	16	30	14	140	12
950	150	18	105	7	104	17	332	25	1,000	90	15	10	15	150	12

The data on the left-hand side are compiled from radio-sonde ascents; those on the right from radar wind observations only.

surface air could have been piled up by convergence, and it is fairly certain that a deep layer was formed with a wet-bulb potential temperature appreciably above 60°F. Fig. 4 shows that this air could have risen to the tropopause.

The rainfall distribution shows that non-orographic rain ranged up to 4·45 in. at Torrington, about half that at Longstone Barrow. The surface NE. wind striking the steep northern slope of Exmoor would necessarily increase the ascending motion through a deep column of already saturated air. The lowest layers would make some direct contribution to the orographic rain since the surface dew point had risen to 58°F. by afternoon owing to the rain over the Bristol Channel.

The favourable combination of factors inevitably led to substantial rainfall, but in the present state of knowledge we cannot differentiate between very exceptional rain and heavy prolonged rain of a more normal type which is often accompanied by thunder. Most heavy rainfall is associated with a new and recent phase of development and with some kind of occlusion process. Even when there are no clearly defined fronts there is evidence that the warmest and dampest air has ascended. In the present case there was a new warm sector which was quickly occluded, and though the warm front was feeble except near the ground over Dorset and Somerset, it was of great importance in relation to the moisture supply. The process of occlusion may affect the track of a depression; it was long ago pointed out by Dr. H. R. Mill that after exceptional rainfall a depression often turns to the right.

Some earlier exceptional rainstorms.—The record daily rainfall for the British Isles, at Bruton, Somerset, fell mostly in the night of June 28–29, 1917. The area with over 4 in., though not a record, was very much larger than in the rainstorm of August 15, 1952. It also was associated with a depression in the English Channel, and there were thunderstorms in an area of continuous rain. There were, however, points of difference from the August 1952 occurrence. The belt of heaviest rain was orientated east-to-west, and had a southern boundary 100 miles from the centre of the depression, which became complex. The belt of heavy rainfall developed in a diffuse frontal zone with colder air spreading slowly south, while a cold front moved east over France but, except in the south-east well away from the heaviest rain, there was no evidence of related trigger action in France, such as happens before most big outbreaks of thundery rain in southern England.

The next largest rainfall, that at Cannington, Somerset, on the night of August 18–19, 1924, was a local fall of a magnitude quite unique in the conditions prevailing. There was a WNW. geostrophic wind of 35 kt. and a dew point a little above 50°F. The heavy hail and rain lasted 4½ hr., and during that time a strip of air about 180 miles long at 2,000 ft. must have crossed the area. Heavy orographic rain requires a suitable initial condition of the air mass, so that there was probably a long chain of showers or at least of large cumulus from the sea. The charts show plenty of showers but no front or trough.

Another notable rainfall in the south-west occurred on the morning of August 4, 1938, when 6 in. fell at some places from Torquay to Dartmoor, in a chain of very violent thunderstorms moving north-west. Temperature exceeded 90°F. in Brittany on the previous day, which is much higher than those associated with the three rainstorms already mentioned.

Discussion of photographs.—Most of the photographs reproduced in the centre of this magazine can be fully appreciated only if they are examined in

relation to the 1 : 25,000 Ordnance-Survey map with their positions and subjects accurately identified. It is then possible from the contours to judge the drainage areas and gradients which produced the effects. The national-grid reference* and direction of view of the camera is given directly beneath each photograph. The 1 in. to the mile Ordnance-Survey map is not quite adequate but can be used for a general survey. A very rough idea of the positions and significance of the photographs may be obtained by using the national-grid-reference border which has been added to Fig. 1. Even on the 1 : 25,000 map (approximately 2½ in. to the mile) a number of the combes which were visited and photographed are not named, so that the references are necessary to identify them. For convenience names derived from other place names in their localities have been attached to these anonymous combes.

On the relatively level ground of the high moor the rainfall had left few marks except for some small patches of flattened vegetation, usually long tough bog grass, and occasional slight erosion or deepening occurring in an old drainage channel or by the side of an embanked hedge. At the heads of the combes the usual ground formation is a shallow trough on the moor leading to a sudden descent into the steep-sided valley, and in these places it was normal for the flattening of the grass in the trough to be very pronounced, with disintegration of the stream-bed in the combe often beginning very high up immediately below the edge of the moorland plateau. Thereafter there was increasing evidence of large volumes of surface water having poured off the moor and rushed down the valleys, deeply eroding the central channel and leaving a high-water mark of flattened or shorn-off vegetation on the banks. The photographs are arranged in approximate order with downstream effects as far as possible toward the end.

Fig. 5.—A general view looking up Woodbarrow Combe, a headstream of a tributary of the West Lyn. Drainage area less than 100 acres.

Fig. 6.—Landslip in Gammon's Combe, a headstream of the most westerly tributary of the East Lyn. The disintegration of the stream-bed begins very high up and the flattening of bog grass in the channel can be discerned. Drainage area less than 100 acres.

Fig. 7.—Erosion partly induced by human activities, about three-quarters of a mile south-west of Simonsbath. Water draining from the upper slopes flowed down a metalled road into the mouth of an old quarry and then overflowed across the road down the hill-side, slope about 1 in 3. The scar on the left seems to be due to water, which percolated through the quarry bottom under the road, emerging because of impermeable strata below.

Fig. 8.—Deep scouring of a moorland cart-track on the eastern side of Shallowford Farm. The second photograph is a close-up of the furthest of the three holes in the general view, and the hump in the foreground obscures a deep depression going down another foot or more. The cart-track runs along a well-defined ridge, and there was virtually no drainage area contributing water other than the track itself.

*All photographs reproduced were taken at points shown on the rainfall map (Fig. 1). This forms part of the 100-Km. square 21 = SS (see "The projection for Ordnance Survey maps and plans and the national reference system", published for the Ordnance Survey, London, in 1951). The remaining figures given below each photograph, four for eastings followed by four for northings, in each case identify a 10m. square within which lies the point from which the photograph was taken, subject to the qualification that the accuracy of any fourth figure is open to slight doubt. The direction of view of the camera is given to the nearest 5° with a similar qualification about the accuracy of the final figure.

Fig. 9.—Disintegration of stream-bed seen from the head of a combe below Dure Down, about $1\frac{1}{2}$ miles north-west of Simonsbath. Dark lumps of peat rubble on the banks indicate the height reached by the flood discharge. Drainage area about 60 acres.

Fig. 10.—The Exe valley looking east from a point about a mile below Exe Head. The width of the valley is about $\frac{1}{2}$ mile, so that along the line of view of the photograph the drainage area ranges upwards from about half a square mile. As the slope of the valley bottom going downstream is much smaller than that for other Exmoor streams disintegration of the channel was not pronounced. The high-water mark of the flood can be seen as the edge of a light patch of flattened vegetation on the left bank of the stream.

Fig. 11.—A spring emerging from beneath the soil at the head of a combe (Tang's Bottom) about two miles north-west of Simonsbath. This sub soil channel, lying immediately above impermeable shale, had carried a very large volume of water and the roof had collapsed for several yards. Overground flow had been even greater, and the combe downstream was one of the most impressive examples of disintegration to be found on the moor. Drainage area above the spring about 50 acres.

Figs. 12 and 13.—Scenes in Cannon Hill Combe, a tributary of the West Lyn, running directly down from the moor near Longstone Barrow. Fig. 12 shows what appeared to be an almost entirely new gorge and waterfall, about one mile north-north-west of the Barrow. Drainage area less than 150 acres. Fig. 13, about 200 yd. further upstream, shows how storm and stream action had breached a footpath over a length and width of more than 12 ft. to a depth of 3–4 ft. The small waterfall in the second photograph enters the pool at the left edge of the first.

Figs. 14 and 15.—Examples of rubble deposited by the floods. Fig. 14 shows Mr. Archer standing on the original stream bank at the side of a mass of peaty earth about 40 ft. × 18 ft. × 5 ft. thick, which had been carried downstream for several hundred yards near the head of Shallowford Combe. About a mile downstream, near Shallowford Farm, was an enormous mass of stone rubble covering a length of about 500 yd. and a maximum width of 70 yd. The second photograph is a general view of the lowest part of this deposit.

Fig. 16.—Discharge of water from a tributary into Long Chains Combe. The torrent indicated by the first photograph had to turn through a right angle on reaching the main combe and in doing so surged in a great curve over the steeply ascending hillside, as shown in the second photograph. Undercutting produced an incipient landslip, and there is a deep fissure which by chance nearly coincides with the top of the high-water mark. Drainage area to this point less than 50 acres.

Fig. 17.—Scenes in Cannon Hill Combe near Woolhanger where there was formerly a small reservoir of capacity 1,500,000 gallons, drained during the flood. The photographs were taken just below the dam (Fig. 17(*a*)), near the dam breached by the flood (Fig. 17(*b*)), and just above the site of the reservoir (Fig. 17(*c*)). Comparison of Figs. 17(*a*) and 17(*c*) shows little to suggest that the draining of the reservoir added much to the volume of water pouring down towards Lynmouth. Calculation of the rainfall, more than 45,000,000 gallons, received above this point (drainage area just over 250 acres) supports this view. Probably not more than 10 per cent. was added to the flow through the reservoir.

Note on drainage.—To interpret data such as those given in Tables I and III in terms of actual flood flow in the streams draining from Exmoor it would be necessary to derive relationships between rainfall and run-off, for the various drainage areas, applicable to the conditions which existed on August 15. It would be out of place to try to develop such relationships in the present note or to attempt any detailed study of the soil, vegetation, topography, and geology of the area which would be a necessary basis. But the investigation brought to light some interesting observations which have a bearing on the problem.

It is apparent from some of the photographs, and was impressively obvious from various points on the moor, that during the period of most intense rain there was a tremendous volume of water pouring from the high ground and raging down the combes. Without going into details it was clear that deep percolation and underground flow were negligible, and that subsoil drainage, though of unusual volume and sufficient to produce upland landslips or contribute to the disintegration of the surface in some of the valleys, did not represent a high proportion of the total run-off. At some point during the evening of the 15th large tracts of Exmoor must have been literally awash to a depth of several inches, the water pouring directly into any convenient depression or trough, to be conveyed very rapidly to the main channels. This was the impression increasingly forced to the mind as more and more of the central area was explored, and it was later confirmed in reports from Pinkworthy Farm, about 1½ miles south-east of Longstone Barrow, and from the high ground near the Exe valley. From the farm it was stated that over the neighbouring slopes the fields were flooded to a depth of 6–8 in. soon after the torrential rain began. It seems beyond doubt that this happened in many parts of the moor, with sheet-flow over extensive surfaces. Normally dormant springs had already burst into activity, according to several accounts, during the heavy falls of the afternoon and early evening, and it seems that this earlier rain, added to substantial falls during the previous fortnight, had been quite sufficient to saturate the land very thoroughly, whilst the brief respite in the early evening with little rain or only moderate falls had not been long enough to ease the situation in this respect. When the torrential rain started it fell on ground which could absorb no more. For this reason alone there is no need to postulate a sudden burst for the outbreak of the main evening fall as the cause of the remarkably sudden floods which descended on Exford and other places. Even with a comparatively gradual build-up in the intensity of this fall the ground probably began to adapt itself to ever more rapid run-off, the channels themselves being improved by the bending or flattening of impeding vegetation and the scouring of all stream-beds. By the time the rain reached its fiercest intensity the rate of run-off was probably almost equivalent to the rate of rainfall over much of the high ground, a state which may have been maintained for some hours with greatly increased rates of travel from the moor into the main channels.

The reports mentioned also support this view in another way. In times of rain since the storm the streams have risen noticeably more rapidly, risen to higher levels, and fallen again more rapidly than before the flood. These observations are consistent with the view that all channels, over ground and beneath the soil, have been cleared and improved by the storm and that rainfall now gathers more quickly into the main streams, only to flow away again more quickly because of similar channel improvement downstream.

It was also reported that on the high ground north-east of Pinkworthy Farm bogs previously impassable by pony had become firm enough to permit passage. The observation is again consistent with the view that drainage has become more efficient as a result of the storm. For any valid assessment of the flood run-off from the rainfall data it is necessary to suppose that drainage was becoming increasingly efficient and rapid during the storm, and especially from the beginning of the four hours or so which were covered by the main evening fall. Such an allowance leads to an appreciably higher estimate of the maximum flood discharge through Lynmouth than any which has so far been put forward.

Acknowledgement.—Discussion of the material available from investigations took place with Mrs. Joyce Gifford, University of Southampton, and Mr. C. Kidson, University College of the South-West, Exeter. The voluntary rainfall observers, within and beyond the area of the rainfall map of this report, contributed many useful data in addition to their routine records, and the general appeal for photographs and other information received a very generous response. Finally the work of Mr. C. H. Archer of Wootton Courtenay, who was assisted by his two brothers, must again be brought to notice.

WORLD METEOROLOGICAL ORGANIZATION

Conference of the Commission for Maritime Meteorology

The first Conference of the Commission for Maritime Meteorology of the World Meteorological Organization was held, appropriately enough, in the lecture hall of the Royal Geographical Society in London. The Conference lasted from July 14 to 29, 1952, and was attended by the delegates and advisers of 21 countries which are Member States of the World Meteorological Organization.

Mr. George Ward, Under Secretary of State for Air, welcomed the delegates on behalf of the British Government, and mentioned, in his address, the important contribution which voluntary observers in merchant ships of many nations make to the science of meteorology by providing observations from the oceans. He added that this voluntary work had been going on for nearly a century, and emphasized its importance not only to the shipping industry but also to all other forms of transport, as well as in connexion with the present world food problems and in its application to other fields of human activity. It was appropriate that this maritime Conference should be held in the ancient Port of London, and Mr. Ward stressed the part which British shipping had played in the peaceful development of world trade.

In his reply the President, Commander C. E. N. Frankcom, said that international maritime meteorology originated in 1854 when Maury organized the first International Meteorological Conference in Brussels. The Commission for Maritime Meteorology of the former International Meteorological Organization held its first meeting in London in 1909. There were at present 2,300 "selected" ships of all nations voluntarily making meteorological observations at sea.

Sir Nelson Johnson, Director of the Meteorological Office, and Dr. Swoboda, Secretary General of the World Meteorological Organization, were present at the opening meeting. The British members of the Commission were Commander J. Hennessy and Captain P. Bracelin. Admiral Termijtelen (Netherlands) was

elected Vice-President for the Conference. Representatives of the International Telecommunications Union and International Air Transport Association were present as observers. Probably the most important task of the Commission was to review and improve, where possible, the network of observations from shipping in all oceans. Prior to the Conference, maps had been prepared showing the known positions of all "selected" ships on a stated day and also the positions from which reports had been received from ships at various meteorological centres throughout the world. During the Conference another map was prepared, with the assistance of the G.P.O. and Lloyd's, showing the known density of shipping in the various oceans. From a study of these three maps it became evident that there are areas where the network is adequate; there are areas where the network is at present inadequate but can be improved; and there are other areas where ships very rarely go and little improvement is possible.

The Commission made recommendations whereby maritime countries should be asked to state whether they could recruit more "selected" ships, particularly in areas where shipping is sparse, and other recommendations were made to rationalize the network generally and improve it.

The Southern Ocean is one area which is of great meteorological importance and in which shipping is always rather sparse. Whaling ships are a fruitful source of information from this ocean, but these ships are always reluctant to disclose their positions to their rivals. A recommendation, proposed by South Africa, was made whereby the whaling ships are supplied with cyphers so that their positions are not disclosed in their radio weather messages. The whaling ships will send their messages to South Africa or Australia, as convenient, and the receiving country, when preparing the message for rebroadcast, will recypher the position and omit the name of the ship in the collective message. All countries in the southern hemisphere will hold the recypher, and will thereby be able to plot the position of the ship without knowing her name, and nobody intercepting the message who does not hold the recypher will be able to know the position of the vessel. By this means it is hoped that Services in the southern hemisphere will have more adequate meteorological information and will be able to issue suitable forecasts for shipping and other purposes. Problems concerning the reception and transmission of radio messages from ships were also considered, and recommendations made with a view to effecting improvements.

The Commission gave considerable study to problems connected with methods of making observations at sea, the exposure and type of instruments used, bearing in mind the special difficulties inherent in a voluntary system of observations aboard ship. Recommendations were made concerning improvements in observational practice. The use of weather ships for making special observations and instrumental experiments was realized, and recommendations were made as to further studies which should be made aboard such ships into such problems as rainfall observation, evaporation, radiation, sea and air temperature, humidity and meteorological factors affecting radio propagation.

The Commission considered that, in general, meteorological information issued for shipping is reasonably comprehensive, but suggestions were made for special radio storm-warning advice in tropical-hurricane areas, and also for additional visual storm warnings at night in these areas. A new international

Ref.: 7120 4297. 030°

FIG. 5—WOODBARROW COMBE

Ref.: 7413 4298. 190°

FIG. 6—LANDSLIP IN GAMMON'S COMBE

Ref.: 7609 3888. 135°

Reproduced by courtesy of Joyce Gifford

FIG. 7—HILLSIDE NEAR SIMONSBATH

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7140 4495, 165°

General view along track

Ref.: 7140 4492, 165°

Close-up of furthest hole

FIG. 8.—CART-TRACK NEAR SHALLOWFORD FARM

FIG. 8.—CART-TRACK NEAR SHALLOWFORD FARM

Ref.: 7543 4080, 260°

FIG. 9—DURE DOWN COMBE

Ref.: 7676 4111, 090°

Reproduced by courtesy of F. Tattersall

FIG. 10—EXE VALLEY NEAR THE HEAD

STORM DAMAGE ON EXMOOR, AUGUST 1952

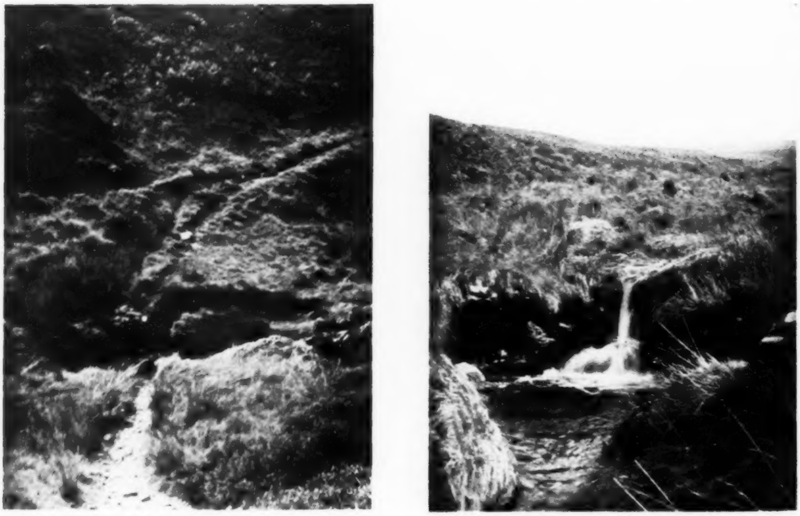
(see p. 353)

Ref.: 7510 4103, 040°

FIG. 11—SPRING FROM SUBSOIL DRAINAGE (TANG'S BOTTOM)

Ref. 7007 4420, 180°

FIG. 12—NEW GORGE AND WATERFALL (CANNON HILL COMBE)



Ref.: 7021 4400, 260°

View along the path

Ref.: 7021 4400, 130°

View upstream

FIG. 13—STREAM DAMAGE ACROSS A FOOTPATH (CANNON HILL COMBE)

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7130 4316, 335°

FIG. 14—PEAT RUBBLE IN SHALLOWFORD COMBE

Ref.: 7124 4472, 030°

FIG. 15—STONE RUBBLE ABOVE SHALLOWFORD FARM

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7447 4220, 190°

Looking up the tributary

Ref.: 7447 4220, 190°

Bank of the main stream opposite the tributary

FIG. 16—TRIBUTARY DISCHARGE IN LONG CHAINS COMBE

FIG. 16—TRIBUTARY DISCHARGE IN LONG CHAINS COMBE

Ref.: 7016 4508, 175°

(*a*) Below Southdown Pond

Ref.: 7015 4501, 185°

(*b*) Breach in the dam

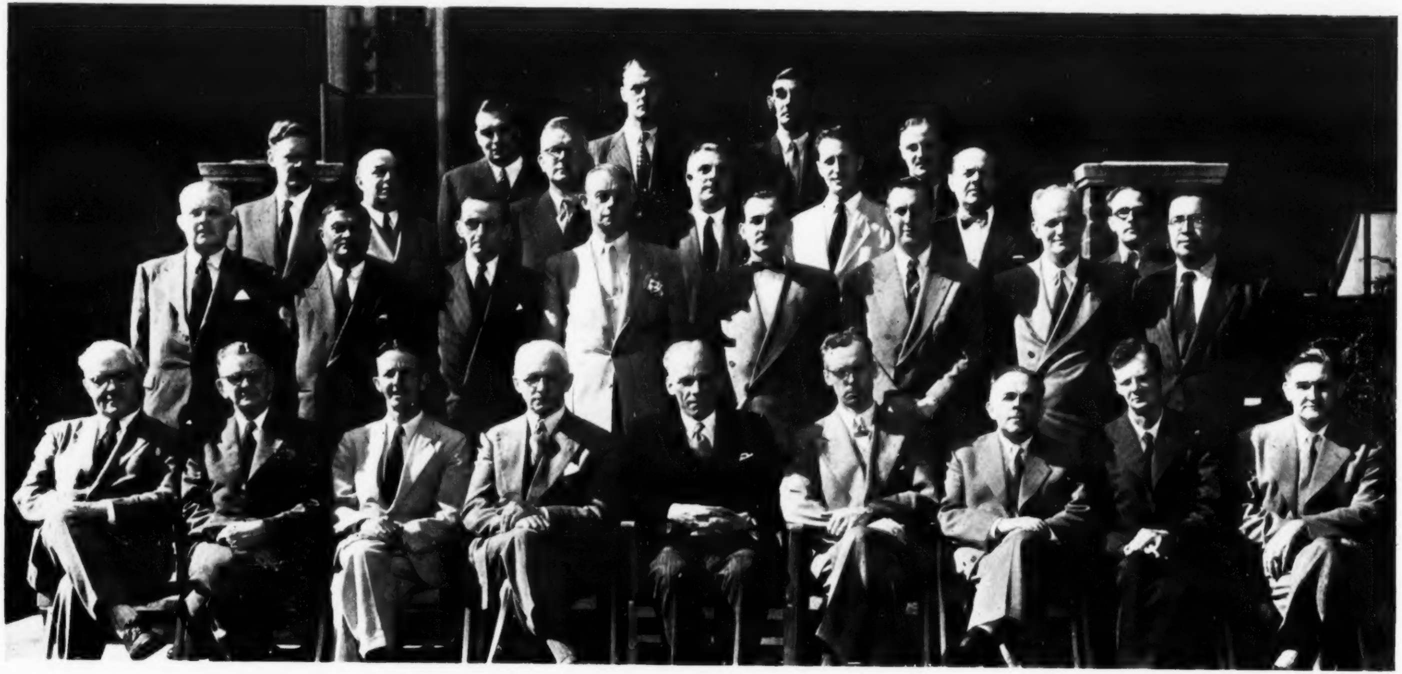
Ref.: 7012 4477, 175

(*c*) Above Southdown Pond

FIG. 17—SCENES IN CANNON HILL COMBE NEAR WOOLHANGER

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)



CONFERENCE OF MARITIME METEOROLOGY, LONDON, JULY 1952

Back row.—Capt. B. F. Benesch (Argentine), R. F. M. Hay (U.K.), J. R. Clackson (B.W. Africa), C. A. S. Lowndes. *Second row.*—H. Thomsen (Denmark), Prof. M. Tenani (Italy), P. M. A. Bourke (Eire), F. Balén García (Spain), J. B. L. Cayetano (Spain), Capt. S. Turcio (Uruguay), Dr. R. Frith (U.K.). *Third row.*—W. Blow (I.T.U.), Dr. B. N. Desai (India), E. Bruzon (France), J. A. Van Duijnen Montijn (Netherlands), Capt. D. Gamez-Calcano (Venezuela), Lieut. C. R. Lluberas (Uruguay), A. Sik (U.S.A.), J. B. de Portugal (Portugal). *Front row.*—W. F. McDonald (U.S.A.), Cmdr. J. Hennessy (U.K.), G. S. P. Heywood (Hongkong), Vice-Adm. J. K. Termijtelen (Netherlands), Cmdr. C. E. N. Frankcom (President), K. T. McCleod (Canada), F. Spinnangr (Norway), A. H. Gordon (W.M.O. Secretariat), Capt. R. O. Minter (U.S.A.).

ice nomenclature was drawn up by a committee of polar experts and recommended for adoption.

A major task was the preparation of general technical regulations of the World Meteorological Organization in the field of maritime meteorology. The preparation of these required the study of innumerable resolutions which had been passed by the International Meteorological Organization and its predecessors since 1872.

In the climatological field the Commission recommended more uniformity in the matter of ships' logbooks in order to facilitate punching the observations on to the new international maritime punch card. A working group was set up to consider improvements which might be effected in the way of international co-ordination in the preparation of maritime climatological atlases.

The application of meteorology to the carriage of goods at sea was considered, bearing in mind the considerable hygroscopic damage which can be caused to cargo in a ship's hold as the vessel encounters varying air and sea temperature and humidity during her voyage. It was felt that this is an important question at present in view of world shortages of food and raw material and rising costs, and the Commission set up a working group to study the question and make recommendations accordingly.

At the conclusion of the Conference, Commander Frankcom and Admiral Termijtelen were elected President and Vice-President respectively.

Members of the Commission expressed great satisfaction with the facilities provided for the Conference. In the way of relaxation the Commission was entertained at a reception given by the British Government at which the Secretary of State for Air was present, and by the Honourable Company of Master Mariners aboard the *Wellington*. Through the kindness of Lord Waverley the Port of London Authority launch *St. Katherine* took the delegates on a trip down the Thames and through the London Docks, where they were able to appreciate at first hand some of the problems associated with instrumental exposure aboard merchant ships. Two British instrument firms also entertained the Commission very hospitably.

The recommendations of the Commission were, for the most part, approved by the Executive Committee of the World Meteorological Organization at their Session in Geneva in September. Steps are now being taken to put the recommendations into effect, and it is hoped that these will make meteorological information from the oceans both more adequate and more accurate.

AERODYNAMIC NUMBERS

Three numbers associated respectively with the names of Mach, Reynolds and Richardson, figure prominently in present-day aeronautical and meteorological literature. These notes have been written to explain as simply as possible the significance of these three numbers to those who have not made a special study of hydrodynamics.

They are all pure numbers, and so differ from quantities such as velocity, to a numerical value of which it is always necessary to add units of measurement such as miles per hour or feet per minute, or lapse-rate of temperature which must be specified in so many degrees Centigrade per kilometre or degrees Fahrenheit per thousand feet.

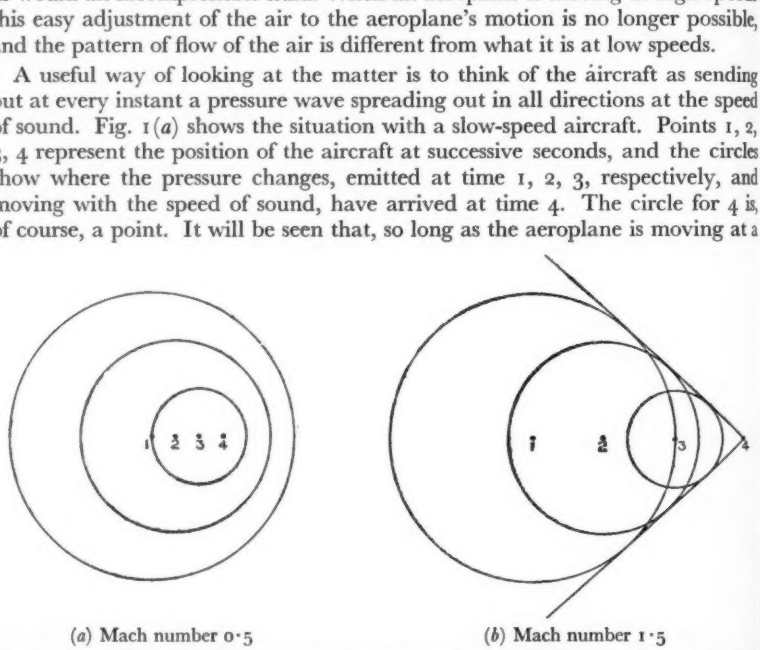
Mach number.—The Mach number is a number of importance in the movement of aeroplanes or projectiles through the air. It is the ratio of the airspeed of the object to the speed of sound. It has always been important in ballistics—the study of projectiles—because bullets and shells move at speeds considerably greater than the speed of sound, and it has become important in aerodynamics with the development of jet-propelled aircraft which can reach airspeeds of over 600 m.p.h. As it is the ratio of two velocities it is obviously a pure number.

Because air is compressible, changes of pressure which are small compared with the total pressure are transmitted at a finite speed. This speed was first measured in connexion with sound and is known as the speed of sound. The speed of sound depends on the temperature, and at temperatures experienced ordinarily at sea level is about 760 m.p.h.

An aeroplane presses on the air ahead which, if the speed of the aeroplane is small compared with the speed of sound, is readily able to adjust itself with only small changes of density or pressure. At such speeds the maximum change of pressure near the aeroplane is approximately equal to ρv^2 where ρ is the air density and v the speed of the aeroplane. From this formula it is easy to calculate that at a speed of 100 m.p.h. the maximum pressure change is approximately 26 mb., that is 2·5 per cent. of the normal atmospheric pressure at sea level.

The air flows round a slow aeroplane in very nearly the same flow pattern as would an incompressible fluid. When an aeroplane is moving at high speeds this easy adjustment of the air to the aeroplane's motion is no longer possible, and the pattern of flow of the air is different from what it is at low speeds.

A useful way of looking at the matter is to think of the aircraft as sending out at every instant a pressure wave spreading out in all directions at the speed of sound. Fig. 1(*a*) shows the situation with a slow-speed aircraft. Points 1, 2, 3, 4 represent the position of the aircraft at successive seconds, and the circles show where the pressure changes, emitted at time 1, 2, 3, respectively, and moving with the speed of sound, have arrived at time 4. The circle for 4 is, of course, a point. It will be seen that, so long as the aeroplane is moving at a



(*a*) Mach number 0·5 (*b*) Mach number 1·5

FIG. 1—FRONTS OF PRESSURE WAVES EMITTED BY AIRCRAFT FLYING (*a*) AT A SPEED LESS THAN THAT OF SOUND, (*b*) AT A SPEED GREATER THAN THAT OF SOUND

lower speed than the speed of sound, the circles, though closer together on the side towards which the aeroplane is moving, will never overlap. If, however, the aeroplane is moving at more than the speed of sound (Mach number greater than 1) the situation takes on the very different complexion shown in Fig. 1(*b*). The circles then overlap, and at any instant they all touch a wedge moving with the aircraft and having its vertex at the leading edge. The pressure changes set up by the motion of the aircraft cannot reach the air ahead so that air is unaffected by the motion. The result is a very different flow pattern from the one prevailing at low aircraft speeds. A surface of compressed air and pressure discontinuity situated along the wedge travels with the aircraft just as a surface wave set up by the bows accompanies a ship. It is easily seen that the sine of half the angle of the wedge equals the reciprocal of the Mach number.

The change in the pattern of flow causes changes in the lift of the wings and in the resistance of the air to the aircraft. The lift and drag are respectively proportional to $C_L v^2$ and $C_D v^2$ where C_L and C_D are quantities called the lift and drag coefficients. They are not constants, but vary very little with airspeed so long as the type of flow does not appreciably change. When the Mach number exceeds about two-thirds, the lift coefficient starts to decrease and the drag coefficient to increase at rates which get larger and larger as the speed increases, so that eventually the lift actually decreases with increasing speed. These changes in the lift and drag coefficients affect the stability of the aircraft and its reaction to the controls. It is vital for the pilots of aircraft which are powerful enough to reach speeds approaching the speed of sound to be warned when the Mach number reaches a high value, because the aircraft may become uncontrollable if it travels too fast. The warning is given by a meter on the instrument board which indicates the Mach number. The dial of the machmeter is shown in Fig. 2. A needle moves over the face in the usual way to indicate the Mach number as a decimal fraction. Special marks are placed on the dial to indicate to the pilot the Mach number he must not exceed.

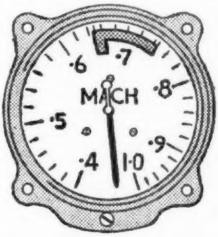


FIG. 2—MACHMETER, MK. I

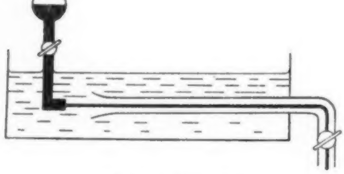
As already mentioned the speed of sound depends on the temperature. In fact, neglecting the minute effects of water vapour, the speed of sound is proportional to the square root of the absolute temperature of the air. In the international standard atmosphere the speed of sound at zero height (temperature 15°C.) is 762 m.p.h. and at 37,000 ft. (−56·5°C.) it is 660 m.p.h. The machmeter had necessarily to be designed to take account of the change of speed with temperature. This was done by using the fact that the Mach number is nearly proportional to the square root of the ratio of the difference

between pitot-head pressure and static pressure to the static pressure. For a full description of the instrument reference should be made to the "Instrument manual (navigational instruments)"[1].

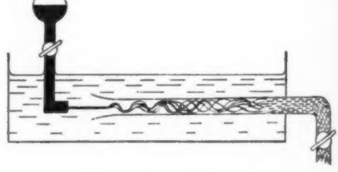
Reynolds number.—The Reynolds number is also important in connexion with the flow pattern of a fluid or gas but at very much lower speeds than those for which the Mach number is important. It is concerned with the transition from stream-line, or laminar, flow to turbulent flow in a fluid without an appreciable temperature gradient.

It originated in experiments made in 1883 by Osborne Reynolds on the flow of water in a narrow tube. Reynolds set water flowing in a horizontal glass tube projecting from a reservoir. A subsidiary thin tube opening into the main one along its centre was arranged to make a thin stream of coloured dye enter the centre of the tube, as shown in Fig. 3.

At low speeds of flow, as shown in Fig. 3(*a*), the dye made a thin steady line along the centre of the tube. The speed of flow was increased by small steps until, quite suddenly, the nature of the flow changed drastically so that instead of the dye forming a steady line it spread out to mix with the water to form a dilute coloured mass filling the tube—Fig. 3(*b*). For a given diameter of tube and fluid Reynolds found there was a critical speed of flow for which the flow pattern changed from laminar to turbulent. Further experiments revealed that the critical speed depends on the liquid and on the size of the tube. Turbulent flow in a given fluid sets in at a lower speed in a wide tube than in a narrow one.



(*a*) Laminar flow



(*b*) Turbulent flow

FIG. 3—APPARATUS USED BY OSBORNE REYNOLDS IN 1883 TO STUDY TURBULENT FLOW IN A LIQUID

These experiments led Reynolds to define the number: $ud\rho/\mu$ in which u, ρ, μ are the speed, density and viscosity of the fluid and d is the diameter of the tube. It can be shown from the theory of dimensions, for which reference should be made to standard textbooks[2,3], that the Reynolds number is a pure number. The symbols employed for the Reynolds number are R or R_e.

Reynolds found that turbulent flow in smooth tubes carefully insulated from external disturbances set in spontaneously when the Reynolds number reached a value of about 2,000. The actual value in any case depends on the shaping of the entry pipe. Thus in a tube of 1 cm. diameter the flow of water at temperature 15°C. ($\mu = 0{\cdot}01142$ gm./sec./cm.) changes from laminar to turbulent at a speed of 23 cm./sec.

Further experiments showed that there is a critical Reynolds number defining the speed at which turbulent flow sets in when a fluid flows past any smooth body such as a sphere or transverse cylinder. The diameter of the

sphere or the cylinder replaces the diameter of the tube in the formula for the Reynolds number. The critical range of values of the Reynolds number for transition to turbulent flow is 2×10^5 to 4×10^5 for flow round a sphere or cylinder and is thus higher than for flow in a tube.

The transition to turbulent flow has repercussions on the resistance of a fluid to a body moving through it as the speed increases through the critical value. The change to turbulent flow produces a sharp drop in the value of the drag coefficient C_D in the formula $C_D v^2$ mainly because turbulence reduces the fall of pressure immediately behind the body.

Meteorological applications of the change in drag coefficient at a critical speed occur in the ascent of balloons and the fall of hailstones. In balloon work the decrease in density of the air with height produces for a given rate of ascent a decrease in Reynolds number with height. Many meteorological balloons have diameters and rates of ascent such that at some parts of the ascent the Reynolds number lies within the critical range for change of flow from turbulent to laminar, and this fact makes it impossible to derive a simple general formula connecting the rate of ascent of the balloon with its weight and free lift. Scrase showed, in an unpublished report, that high-altitude 2-Kg. balloons pass through the critical value of Reynolds number at heights between 10 and 15 Km. The Reynolds number decreases so that turbulent flow round the balloon is replaced by laminar flow, and the rate of ascent decreases because of the rise in drag cofficient. The change from a value of Reynolds number of $6 \cdot 7 \times 10^5$ at 10 Km. to one of $1 \cdot 7 \times 10^5$ at 20 Km. is associated with a fall in speed of ascent from about 1,500 to 1,000 ft./min. Bilham and Relf[4] have studied the fall of hailstones and shown by equating the weight to the drag that the change in drag coefficient of a sphere in the critical range of Reynolds numbers makes it possible for hailstones, within certain ranges of size depending on the density of the hail, to have two terminal speeds. The higher of these two speeds is associated with the lower drag coefficient but is so great, at 300–400 ft./sec., that it is considered very unlikely that it ever occurs. It is concluded that there is an upper limit of about 200 ft./sec. to the rate of fall of a hailstone. This occurs with one of mass about $1 \cdot 5$ lb. which is considered to be the largest possible size.

Richardson number.—Turbulence in a fluid may be generated by motion over solid bodies to which the Reynolds number theory applies. In a compressible fluid it is also possible for turbulence to arise spontaneously when there are variations of speed of flow, or of density, or both, within the fluid. A theory of the development of spontaneous turbulence was put forward by L. F. Richardson in 1920, and this theory introduces a non-dimensional quantity now called Richardson's number and usually designated by R_i.

In an atmosphere in which temperature falls with height at a rate greater than the adiabatic value, the ordinary theory shows that a "bubble" once starting to move vertically will be accelerated by buoyancy, because at any level it will be lighter than the surrounding air if moving upwards and heavier than the surrounding air if moving down. In such an atmosphere turbulence readily arises.

In an atmosphere of lapse rate less than the adiabatic value a "bubble" set moving vertically will be slowed down by buoyancy and it is not clear at first

sight how turbulence can be spontaneously generated. Spontaneous generation of turbulence is possible, however, if there is a sufficient variation of horizontal wind speed with height. Suppose the horizontal speed increases with height as it nearly always does in the lower layers of the atmosphere. Then an upward-moving eddy will carry up slower-moving air and so tend to produce a local reduction of speed as it mixes with air higher up. Similarly a downward-moving eddy will tend to produce a local increase in speed. These local irregular reductions or increases of the general flow constitute turbulence.

We have to consider the kinetic energy of turbulence which, per unit volume, is proportional to $\rho(u - \bar{u})^2$ where u is the actual horizontal speed and $\bar{u}$ the mean horizontal speed at the height considered. As an eddy moves up or down in a stable layer it loses energy because it has to move against the buoyancy, but if the gain in the kinetic energy of turbulence produced by the movement into a layer of different mean speed exceeds the energy lost by the movement of the eddy against buoyancy, then turbulence will tend to increase.

It can be shown that the mean rate of gain of turbulent kinetic energy by a large number of eddies is, per unit volume, proportional to $K_M \ \rho(d\bar{u}/dz)^2$ in which K_M is the coefficient of turbulent diffusion of momentum and $d\bar{u}/dz$ is the rate of increase in mean speed with height. The usual adiabatic convection theory shows that a "bubble" rising through a small distance l will be at a temperature lower than the temperature of its surroundings by the amount $l(dT/dz + \Gamma)$ where dT/dz is the rate of increase of temperature with height and Γ is the adiabatic lapse rate. From this it follows that the density of the "bubble" is greater than the density of the environment by the amount

$$\frac{l\rho}{T}\left(\frac{dT}{dz} + \Gamma\right),$$

whence Archimedes' theorem shows that the downward force per unit volume on it is

$$\frac{gl\rho}{T}\left(\frac{dT}{dz} + \Gamma\right).$$

If w is the vertical velocity, the amount of work done against buoyancy in the upward flow is thus

$$\frac{g}{T}\left(\frac{dT}{dz} + \Gamma\right)\overline{wl}$$

for unit horizontal area per second taking the mean over many eddies. The mean value of vertical velocity multiplied by distance travelled by the eddy $\overline{wl}$, is the coefficient K_T of turbulent diffusion of heat. The ratio K_T/K_M is believed not to differ appreciably from unity in the atmosphere. The ratio of the rate of loss of potential energy to the rate of gain of turbulent kinetic energy is the Richardson number, and is given by the ratio,

$$g\left(\frac{dT}{dz} + \Gamma\right) \Big/ \ T\left(\frac{d\bar{u}}{dz}\right)^2.$$

It is easily proved from dimensional theory that the Richardson number is a pure number. This theory suggests that turbulence will tend to increase in intensity if R_i is less than unity and decrease if it is greater than unity.

Laboratory investigations suggest a critical value of R_i as low as 0·04. On the meteorological scale it is difficult to determine R_i and decide whether turbulence is increasing or decreasing. Critical values of between 0·04 and 1·0 have been given for the lower atmosphere by various workers. In the free atmosphere calculation is possible only from observations over rather large height ranges. Bannon's data[5] suggest that the maximum of the frequency distribution of R_i is about 10, and that values of over 1,000 are by no means infrequent. No definite information is available on the critical value of R_i in the free atmosphere, but it is significant that Bannon[6,7] found that bumpiness encountered by aircraft in clear air at great heights is often associated with a large vertical wind shear (i.e. large du/dz) and with correspondingly low values of R_i in the range from 1 to 5.

For further study on the subjects of these notes, readers could hardly do better than turn in the first place to the two small books by O. G. Sutton[8,9] listed below. "The science of flight" is the more elementary of the two.

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PILOT-BALLOON OBSERVATIONS IN THE SUDAN

By U. C. W. RATH

The opening of regular jet-plane passenger services over the Sudan in May 1952 made upper wind observations necessary to heights of 30,000–40,000 ft. in a country over which, it was believed until a few years ago, duststorms, haze and strong upper winds, as well as tropical thunderstorms, made direct observations by means of pilot-balloon ascents to such high levels impossible.

In "Upper winds over the world"[1], the reasons why pilot balloons are lost were investigated for a number of stations all over the world, and it was considered that Khartoum was a typical example of a hazy and dusty atmosphere. In their paper the authors chose Khartoum (November 1935–October 1936) as an example of difficult atmospheric conditions where the observed frequencies of upper wind would require large corrections for balloons lost because of poor visibility and strong upper winds[1]. Actually 49 per cent. of all balloons were lost below 10,000 ft. during the period investigated by Brooks. Since then the mean height reached by pilot balloons has increased steadily. Table I gives some typical examples for the period 1939–51.

The improving standard of observations shown in Table I is not due to climatic changes but to the better training and longer experience of the

TABLE I—MEAN HEIGHT OF PILOT BALLOON ASCENTS AT KHARTOUM

	Number of ascents	Mean height at which balloons were lost by all observers	by the best 3 observers
		ft.	ft.
1935–36	623	10,000	...
1939–40	730	13,000	16,000
1944–45	730	11,500	13,000
1950	1,039	16,500	22,500
1951	1,160	18,000	23,500

observers, who have to follow balloons without protection against the sun or the wind at temperatures often exceeding 100–110°F.

Nevertheless only a few of the 40 daily ascents from 14 Sudan stations reach the required heights, and the reasons for the loss of balloons at lower levels are not always easy to detect. Observations of the oblique visibility of the ground from aircraft would be one measure of the haziness but very few are available, and even these few are not considered very reliable because of the scarcity of visibility marks and fixed points for navigation over the desert. Table II gives the best data for Khartoum based upon observations made during regular twice-daily aeroplane ascents in the winter of 1945–46.

TABLE II—VISIBILITY REPORTED FROM REGULAR AIRCRAFT ASCENTS OVER KHARTOUM, WINTER 1945–46

Height of aircraft (ft.)	6,000	10,000	14,000
Approximate mean visibility (miles) ...	20	30	40

The observations are in fair agreement with reports from the pilots of commercial aircraft and with observations by meteorologists during occasional flights over the Sudan in such aircraft. It is interesting to compare these normally very good slant visibilities with the mean distances up to which high-level pilot balloons would have to be followed to obtain wind data to heights of 10,000, 20,000, 30,000 and 40,000 ft. In the third column of Table III the horizontal components of the distances from the balloon to its point of release are given, while the last column states the actual slant distances. It will be seen that on the average the difference between the horizontal component and the actual slant range, i.e. the difference between columns 3 and 4, is of the order of 0·5–1·3 miles only.

TABLE III—APPROXIMATE MEAN DISTANCES OF PILOT BALLOONS WHEN OBSERVED AT DIFFERENT HEIGHTS OVER KHARTOUM

Period: 1950–51

Height	Time since release	Mean horizontal distance	Mean slant distance
ft.	min.	miles	miles
40,000	80	21	22·3
30,000	60	13	14·2
20,000	40	8	8·9
10,000	20	3	3·5

Table III is based on a preliminary analysis of upper winds at Khartoum. It is hoped that full details of this analysis will be published in the near future.

Even if allowance is made for the inevitable inaccuracies of both visual observations from aircraft in flight and of pilot-balloon observations, Tables II and III suggest that the limitations of visibility by dust and haze are normally not nearly as bad as was thought in former years. In fact, with good theodolites and balloons of suitable size and quality, atmospheric conditions over Khartoum

normally make it possible to follow pilot balloons to distances two or three times those hitherto attained.

An analysis of the results of all 14 Sudan pilot-balloon stations has shown that three main factors are of considerable influence on the heights attained:—

(i) Seasonal variation with a pronounced maximum during the clear and comparatively cool winter months and with a minimum during the cloudier as well as very hot and trying summer months. As an example records from Wadi Halfa (21°55′N., 31°20′E., height 410 ft.), Khartoum (15°37′N., 32°32′E., height 1,247 ft.) and Juba (4°51′N., 31°37′E., height 1,509 ft.) for 1950 and 1951 are shown in Fig. 1. Since all stations are of about the same longitude this graph may be regarded as a meridional cross-section through the Sudan from 5°N. to 22° N.

(ii) Time of day.—The 0300 G.M.T. and 0900 G.M.T. (0500 and 1100 Sudan time) balloons show the best results, while during the very hot and (in summer) cloudier afternoons the mean heights show a marked decrease. The lowest results are obtained at night (2100 G.M.T. or 2300 Sudan time) when most of the balloons reach about 10,000 ft. and only a few exceed 15,000 ft.

(iii) Superimposed on these seasonal and diurnal variations is a wide scatter from station to station and generally from observer to observer. It has been found very difficult, so far, to separate the decrease in the heights attained during the summer months or in the afternoon due to weather (such as thunderstorms and duststorms, cloud, thick haze and strong winds) from that due to other random causes.

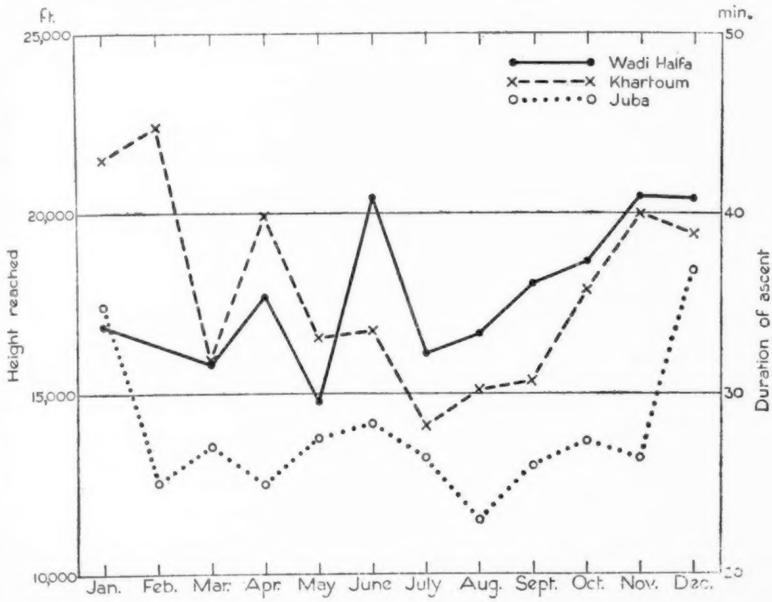

FIG. 1—MEAN HEIGHT REACHED BY PILOT BALLOONS OVER THE SUDAN, 1950–51

Since the frequency of duststorms, thick haze and thunderstorms, is less than 5 per cent. at Khartoum and in the arid and desert zones of the country (i.e. north of about 13°N.), even during the worst times of the year, it is hoped that with better equipment, faster-rising and bigger balloons, and improved training of observers, a further substantial improvement in the number of upper wind observations at the required heights of 30,000–40,000 ft. will be possible.

The writer is indebted to the Sudan Government Meteorologist for permission to publish this note and for his valuable suggestions during the preparation of it.

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LETTER TO THE EDITOR

Ageostrophic mean flow

Mr. Crossley's demonstration[1] that the spatial mean ageostrophic departure is related to the vector variance is as important as it is elegant. That a normal wind distribution is assumed should not be regarded as too limiting, for we can at least be satisfied with knowing the magnitude of these ageostrophic flows. Sooner or later the problem of ageostrophic flows arising from skewed wind distributions will have to be faced, but the "normal" assumption is obviously the first step.

Mr. Crossley's work emphasizes again the great importance of the vector wind variance as a meteorological parameter. This quantity was first measured by Brooks and co-workers[2] as a model of wind structure alternative to the ungainly wind-rose. The aim was largely practical, connected with flight planning, safe fuel loads, etc., but the value of σ is by no means confined to these fields.

In the present application it is possible to measure simply one component of ageostrophic mean flow. The measurement of ageostrophic flows is of obvious importance in dynamic meteorology, particularly in connexion with the global circulation.

The wind variance may also be applied to the mean kinetic energy per unit mass at a point. Over a period this is given by

$$\tfrac{1}{2}\overline{\mathbf{V}^2} = \tfrac{1}{2}\mathbf{V}_m{}^2 + \tfrac{1}{2}\sigma^2.$$

For a number of perturbations in a steady flow, $\frac{1}{2}\mathbf{V}_m{}^2$ represents the kinetic energy inhering in the general flow, and $\frac{1}{2}\sigma^2$ the kinetic energy of the perturbations. The vector wind variance is thus a measure of the "activity" of migrating disturbances in a given area. We may distinguish a high-index situation as one in which most of the kinetic energy derives from the general flow, or $|\mathbf{V}_m|/\sigma$ is large, whilst in a very low-index situation most of the kinetic energy will be derived from the perturbations, and $|\mathbf{V}_m|/\sigma$ will be small. This suggests that we might take $|\mathbf{V}_m|/\sigma$ as an index of the general flow rather than a mean wind between two latitudes. It is, in general, advantageous to have a dimensionless parameter for an "index".

Another application of the wind variance is to the vertical structure of perturbations. The way in which σ varies with height tells us something about the mean vertical structure of disturbances[3].

Whether such applications would prove of value to the practical forecaster or not, it is apparent that many problems, particularly in connexion with the mean global flow, can be formulated simply and elegantly with the aid of the vector variance.

R. W. JAMES

27 Dora Road, S.W.19, September 4, 1952

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NOTES AND NEWS

Thunderstorm of November 19, 1950, at Singapore

During the early hours of November 19, 1950, a good example of the more active type of equatorial thunderstorm was observed from Tengah, Singapore. This storm gave heavy rain, a total fall of 111·3 mm.* occurring between 0100 and 0700 zone time (G.M.T. + 7) of which 73 mm. fell between 0300 and 0400, and 102·2 mm. between 0300 and 0500. Zone time is half an hour behind local time.

This storm produced extensive flooding over Singapore island, mainly in the northern and western parts.

Of five other heavy falls of rain at Tengah since January 1, 1950, which each gave 60 mm. or more over a period of 5 hr., the mean fall in 5 hr. was 69 mm. and the maximum 82 mm., whereas the storm under review in this note gave 110 mm. during a corresponding period.

Lightning was first observed to the south from Tengah at 1900, together with a lunar halo. Lightning continued to the south and south-west during the following hours, becoming quite vivid and very frequent by 2300. During this period stratocumulus cloud was spreading into the Tengah area from the south-west. Although by midnight the lightning had become less frequent, the storm cells were steadily advancing towards the airfield and thunder was heard at 0028. Cumulonimbus clouds were now visible to the south-west.

	Weather	Surface wind		Temperature	Relative humidity	Rainfall during previous hour	
		° true	kt.	° F.	%	mm.	in.
0000	cl	040	1	74·7	96	—	—
0100	ctl	240	2	74·3	96	—	—
0200	tlr_0	250	2	74·0	98	1·3	0·05
0300	tlr_0	250	1	74·1	99	0·1	0·004
0400	TLR	240	4	73·5	100	73·0	2·87
0500	TLR	250	6	73·3	100	29·2	1·15
0600	rr	230	4	73·8	97	5·8	0·23
0700	r_0r_0	260	1	74·1	100	1·9	0·07

By 0100 a storm cell to the west-south-west was again giving very frequent lightning, accompanied by thunder, and rain commenced at 0106. This proved to be only a light fall, the storm centre passing to the west of the station, with the lightning becoming less frequent. The rain shower ceased at 0220. Upper cloud, associated with cumulonimbus, increased to 4 oktas of alto-cumulus.

* 25·4 mm. = 1 in.

More thunderstorm cells were lying to windward, however, and the rain recommenced at 0257, intensifying to moderate by 0306. This fall probably came from the leading edge of a multi-cell storm of fairly extensive proportions, which was extremely active and passed slowly over Tengah. The rain became very heavy by 0315, with almost continuous, and vivid, lightning in all directions.

Heavy rain, with lightning, continued until 0510 and then eased to moderate intensity, as the main storm centre moved slowly away towards the north. By 0700 there was only continuous light rain falling from altostratus cloud.

The surface wind throughout was from 240–250°, 2–6 kt., but with a gust to 18 kt. at 0515.

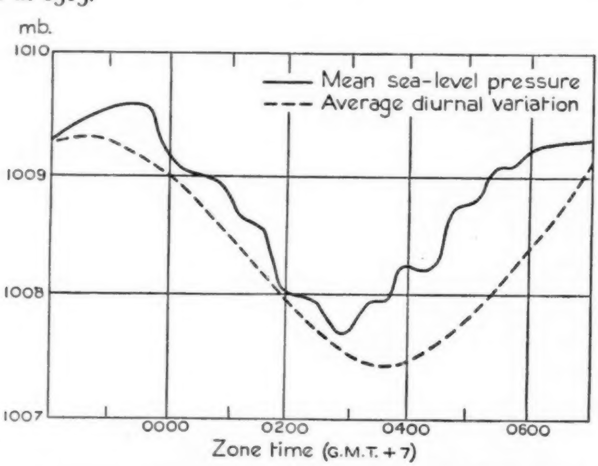

FIG. 1—BAROGRAM FOR TENGAH, NOVEMBER 18–19, 1950

Fig. 1 is a reproduction of the actual barogram during the period, the lower curve representing the average diurnal pressure variation. Fluctuations associated with the passage of individual storm cells are well marked.

This storm was associated with the intertropical convergence line, which, after lying to the south-west of Singapore, had moved quickly north-eastwards on November 18. Activity was probably intensified as the convergence line traversed the Malacca Straits to cross the island in the early hours of November 19.

The southern half of the Straits of Malacca is a notorious area of local nocturnal convergence and thunderstorm activity. The Straits seem to exercise a "booster" effect at night time upon transient cumulonimbus clouds.

P. G. RACKLIFF

REVIEWS

Soviet plans for irrigation and power: a geographical assessment. By A. A. Grigoryev. *Geogr. J., London,* **118,** 1952, pp. 168–179.

Academician Grigoryev's article in the June 1952 number of the *Geographical Journal* is concerned mainly with plans for the utilization of the water of the great rivers of the U.S.S.R. for irrigation and the generation of electric power.

He includes a short note on the climatic effect of wind-breaks, which shows that in the areas of the U.S.S.R. which, as in the lower Volga region, are arid but not desert, the main advantages expected from wind-breaks lie in a reduced outflow of snow-melt water and more uniform distribution of soil moisture produced by a more uniform distribution of snow cover. For this reason the wind-breaks in these areas are arranged to provide appreciable penetrability to the wind. Impenetrable wind-breaks produce a very uneven distribution of snow. In the desert areas wind-breaks are of use only in irrigated areas and are planted round oases to reduce the influx of dry desert air. In the irrigated and sheltered oases evaporation gives a July mean temperature 3°C. lower than over the desert, but more important is the reduction in the midday July surface-soil temperature from 65°C. in the desert to 35°C. in the irrigated fields of the oasis.

G. A. BULL

Report on the Snow Survey of Great Britain for the season 1950–51. By E. L. Hawke and D. L. Champion. *J. Glaciol., London,* **2,** 1952, pp. 25–38.

This report by Mr. E. L. Hawke and Mr. D. L. Champion, Directors of the Snow Survey, describes the snow condition of the snowiest winter since the one of 1946–47. Observations made from Banavie of the snow cover on Ben Nevis are included for the first time, and reveal that there was continuous snow cover above 3,500 ft. on that mountain from October 30 to May 30. The higher summits of the Snowdon group were continuously covered from November 12 to May 31. Snow showers occurred as late as May 15 on Dartmoor. The report is illustrated with excellent photographs of a snowfield on Ben Macdhui in the Cairngorms in late July 1951 and of very heavy rime during April on a snowfield in the Cairngorms.

G. A. BULL

OBITUARY

Francis James Chaplin.—We regret to record the death of Mr. F. J. Chaplin on October 25, 1952.

Mr. Chaplin joined the staff of the meteorological office attached to the Artillery Ranges at Shoeburyness in April 1921 and remained there for more than eleven years. In 1932 he transferred to synoptic work at the civil aerodrome at Croydon and from 1936 to 1938 he served in the Climatological Branch at Headquarters. After further service at civil aviation stations he went to Canada in March 1942 to serve with the meteorological unit attached to an Advanced Navigation School. On return to England in the autumn of 1943 he filled successively a number of administrative posts at R.A.F. Groups until he went to Morton Hall in 1947 on the inception of No. 21 Group, Flying Training Command. Beginning with a small nucleus of stations in eastern England, he saw the Group expand to treble its original size.

Mr. Chaplin was particularly suited for administrative work at a Group Headquarters. He lightened the load of Senior Meteorological Officers by his close attention to detail and the good relations he maintained with staff at the subsidiary offices.

Mr. Chaplin enjoyed country life. He was a great walker and cyclist, swam often, and had latterly renewed an early interest in riding. This interest followed on from his service in a Yeomanry Regiment during the 1914–18 war. His sudden illness and unexpected death came as a great shock to all who had known him.

METEOROLOGICAL OFFICE NEWS

Courses for climatological observers.—Two courses for climatological observers were held in October 1952, each attended by twenty-five observers from amongst the crop weather stations, health resort stations and normal climatological stations. Lectures were given by the staff of the Meteorological Office Training School, Stanmore, on making and recording observations and on the lay-out, care and maintenance of instruments. Attention was also given to the particular interests of the crop weather stations and health resorts. Finally the observers spent a day at the meteorological office at Harrow where the procedures for dealing with returns in the Climatological Branch and of testing instruments by the Instruments Branch were explained to them.

This is the third successive year that such courses have been held, to the mutual advantage of the observers and the Office.

Swimming.—At the Air Ministry swimming gala held at Marshall Street Baths on October 22, the Meteorological Office won the departmental relay race for the fifth consecutive year.

Miss D. M. Vinney, a newcomer to the Office, was second in the Ladies' Championship.

WEATHER OF OCTOBER 1952

Mean pressure was below normal over the North Atlantic and west Europe but above normal over north Scandinavia, the Arctic Ocean and most of the United States except the extreme east. The lowest mean pressure, 998 mb., occurred south-east of Greenland and was 7 mb. below normal, while the mean pressure at the Azores, 1017 mb., was 4 mb. below normal. Mean pressure over north Finland reached the high value of 1021 mb., as much as 11 mb. above normal; over the United States mean pressure was uniform around 1020 mb. and generally 3 mb. above normal.

Mean temperature was 30°F. in Finland (5°F. below normal), 40–50°F. in Europe (2–3°F. below normal) but in the Mediterranean region the mean temperatures between 60° and 70°F. were about 2°F. above normal. In the United States, mean temperature was high in the west and south-west; in Arizona it exceeded 70°F. and was 5°F. above normal.

In the British Isles the cold weather experienced in September persisted during the first three weeks of October, while the last ten days were unsettled and rather mild. Broadly speaking rainfall was less than the average over most of the east of Great Britain and at many places on or near the west coast, while more than the average occurred in central districts of Great Britain and in Ireland.

On the 1st a depression moved north-east from the Strait of Dover to the southern North Sea giving rain, chiefly in the southern and eastern districts of Great Britain. Thereafter a ridge of high pressure off our north-west coasts moved south-east and was followed by a trough. Showers occurred, chiefly in the north and west, but there were long bright periods locally, particularly in the west. On the 5th a ridge extending from an anticyclone on the Atlantic moved south over our southern districts and bright weather prevailed for the most part in England, Wales and Ireland, while a trough gave cloudy, showery weather in Scotland. On the 6th a deep depression centred north of Scotland

moved east and later turned south-east to the Skagerrak and a short spell of westerly to northerly winds ensued with scattered rain or showers but long, sunny periods in many places. By the 8th an anticyclone was situated over southern Ireland giving a mainly sunny day over southern districts but a trough, associated with a depression moving east from Iceland to Norway, caused rain in northern districts on the 8th and slight scattered rain or showers on the 9th. Subsequently an anticyclone moved from westward of Ireland to Scandinavia and a short cold, fair spell occurred with some low minimum temperatures; air temperature fell to 24°F. at Shawbury on the morning of the 11th and at Elmdon on the 12th. A trough gave considerable rain in the west on the 12th, while a deep depression crossing southern England on the 13th was associated with heavy rainfall over a large area and a gale in places. Another ridge of high pressure followed with further widespread early morning frost and fog. Temperature fell to 23°F. at Eskdalemuir on the 15th and to 24°F. at Elmdon on the 16th. Weather continued mainly fair in the east until the 18th with some rise in temperature. On the 18th and 19th a trough of low pressure off our south-west coasts moved slowly east giving rain in most parts; winds backed to south-east and the 19th was a cold, mainly wet day. Meanwhile the anticyclone over Scandinavia persisted and mainly dull, cold weather prevailed on the 20th and 21st. A spell of unsettled, milder weather ensued which lasted until the end of the month. On the 22nd and 23rd a deep Atlantic depression approached our north-west coasts, while troughs moved north-east across the country giving rain and local thunderstorms; gales occurred in places in the north and north-west. At Ternageeragh, near Upperlands, Co. Londonderry, a tornado caused considerable damage on the 23rd. Subsequently the main depression moved east-north-east to the north of Scotland and filled; widespread thunderstorms occurred on the 24th and showers on the 25th and 26th. On the 27th a trough associated with an intense depression on the Atlantic (pressure at the centre about 940 mb.) moved north-east over England giving heavy rain in the west on the night of the 26th–27th and more generally on the 27th (2·61 in. at Thirlmere, Cumberland, 2·53 in. at Llyn-y-fan Fach, Carmarthenshire, and 2·45 in. at Halifax, Yorkshire, on the 27th). The main depression subsequently moved north-east off our north-west seaboard causing widespread rain and gales, which were severe on our north-west coasts (3·48 in. of rain fell at Glenquoich, Inverness-shire, on the 28th). The rain was followed by showers, local thunderstorms and sunny periods. Further rain spread into the west on the 31st and right across the country during the night.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	64	21	−1·4	105	−1	104
Scotland	66	22	−1·0	106	0	116
Northern Ireland ...	61	27	−0·6	133	+1	133

RAINFALL OF OCTOBER 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·61	99	*Glam.*	Cardiff, Penylan ...	5·71	120
Kent	Folkestone, Cherry Gdn.	3·05	76	*Pemb.*	Tenby	4·18	85
,,	Edenbridge, Falconhurst	2·91	81	*Mer.*	Aberdovey	5·80	122
Sussex	Compton, Compton Ho.	6·68	146	*Radnor*	Tyrmynydd	6·87	104
,,	Worthing, Beach Ho. Pk.	3·16	87	*Mont.*	Lake Vyrnwy	10·63	182
Hants.	Ventnor Cemetery ...	4·29	107	*Mer.*	Blaenau Festiniog ...	8·25	81
,,	Southampton (East Pk.)	5·03	128	*Carn.*	Llandudno	3·89	116
,,	Sherborne St. John ...	4·18	119	*Angl.*	Llanerchymedd ...	4·37	97
Herts.	Royston, Therfield Rec.	2·16	79	*I. Man*	Douglas, Borough Cem.	4·86	107
Bucks.	Slough, Upton	2·84	101	*Wigtown*	Newton Stewart ...	4·24	94
Oxford	Oxford, Radcliffe ...	3·76	130	*Dumf.*	Dumfries, Crichton R.I.	5·40	137
N'hants.	Wellingboro' Swanspool	2·69	107	,,	Eskdalemuir Obsy. ...	5·07	94
Essex	Shoeburyness	1·30	55	*Roxb.*	Kelso, Floors	3·21	110
,,	Dovercourt	1·61	67	*Peebles*	Stobo Castle	3·91	113
Suffolk	Lowestoft Sec. School ...	1·76	63	*Berwick*	Marchmont House ...	3·47	91
,,	Bury St. Ed., Westley H.	2·83	104	*E. Loth.*	North Berwick Res. ...	1·30	44
Norfolk	Sandringham Ho. Gdns.	2·22	73	*Midl'n.*	Edinburgh, Blackf'd. H.	1·46	51
Wilts.	Aldbourne	4·64	137	*Lanark*	Hamilton W. W., T'nhill	2·04	63
Dorset	Creech Grange	5·59	110	*Ayr*	Colmonell, Knockdolian	4·57	103
,,	Beaminster, East St. ...	5·32	120	,,	Glen Afton, Ayr San. ...	6·25	123
Devon	Teignmouth, Den Gdns.	5·36	139	*Renfrew.*	Greenock, Prospect Hill	6·64	131
,,	Cullompton	4·86	118	*Bute*	Rothesay, Ardencraig ...	5·50	125
,,	Ilfracombe	4·90	107	*Argyll*	Morven (Drimnin) ...	7·14	119
,,	Okehampton Uplands ...	5·92	98	,,	Poltalloch	6·80	138
Cornwall	Bude, School House ...	5·07	125	,,	Inveraray Castle ...	8·43	120
,,	Penzance, Morrab Gdns.	4·42	95	,,	Islay, Eallabus	4·55	95
,,	St. Austell	7·63	145	,,	Tiree	4·56	100
,,	Scilly, Tresco Abbey ...	3·02	79	*Kinross*	Loch Leven Sluice ...	2·86	83
Glos.	Cirencester	4·65	140	*Fife*	Leuchars Airfield ...	2·60	100
Salop	Church Stretton ...	4·92	134	*Perth*	Loch Dhu	7·96	111
,,	Shrewsbury, Monksmore	3·57	127	,,	Crieff, Strathearn Hyd.	3·88	99
Worcs.	Malvern, Free Library ...	4·77	160	,,	Pitlochry, Fincastle ...	4·34	133
Warwick	Birmingham, Edgbaston	4·19	151	*Angus*	Montrose, Sunnyside ...	2·09	76
Leics.	Thornton Reservoir ...	2·88	102	*Aberd.*	Braemar	5·34	142
Lincs.	Boston, Skirbeck ...	1·93	70	,,	Dyce, Craibstone ...	2·67	79
,,	Skegness, Marine Gdns.	2·06	75	,,	New Deer School House	2·67	70
Notts.	Mansfield, Carr Bank ...	3·66	120	*Moray*	Gordon Castle	2·28	72
Derby	Buxton, Terrace Slopes	5·69	116	*Nairn*	Nairn, Achareidh ...	1·58	69
Ches.	Bidston Observatory ...	3·20	98	*Inverness*	Loch Ness, Garthbeg ...	4·76	133
,,	Manchester, Ringway ...	3·35	108	,,	Glenquoich	15·30	153
Lancs.	Stonyhurst College ...	3·53	79	,,	Fort William, Teviot ...	8·77	124
,,	Squires Gate	3·36	95	,,	Skye, Broadford ...	7·93	104
Yorks.	Wakefield, Clarence Pk.	3·55	124	,,	Skye, Duntuilm ...	6·43	118
,,	Hull, Pearson Park ...	2·42	81	*R. & C.*	Tain, Tarlogie House ...	2·13	77
,,	Felixkirk, Mt. St. John ...	4·14	144	,,	Inverbroom, Glackour ...	8·81	156
,,	York Museum	2·44	91	,,	Achnashellach	9·88	130
,,	Scarborough	2·14	68	*Suth.*	Lochinver, Bank Ho. ...	4·24	92
,,	Middlesbrough	2·21	74	*Caith.*	Wick Airfield	3·49	118
,,	Baldersdale, Hury Res.	3·65	98	*Shetland*	Lerwick Observatory ...	3·75	95
Norl'd.	Newcastle, Leazes Pk. ...	2·77	90	*Ferm.*	Crom Castle	3·95	122
,,	Bellingham, High Green	3·05	78	*Armagh*	Armagh Observatory ...	3·87	142
,,	Lilburn Tower Gdns. ...	3·63	98	*Down*	Seaforde	6·13	172
Cumb.	Geltsdale	2·85	77	*Antrim*	Aldergrove Airfield ...	3·11	104
,,	Keswick, High Hill ...	5·67	101	,,	Ballymena, Harryville ...	4·10	111
,,	Ravenglass, The Grove	4·77	110	*L'derry*	Garvagh, Moneydig ...	5·03	143
Mon.	Abergavenny, Larchfield	6·27	150	,,	Londonderry, Creggan	4·45	121
Glam.	Ystalyfera, Wern House	6·10	89	*Tyrone*	Omagh, Edenfel ...	5·61	153

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In.	Per cent. of Av.
·71	120
·18	85
·80	122
·87	104
·63	182
·25	81
·89	116
·37	97
·86	107
·24	94
·40	137
·07	94
·21	110
·91	113
·47	91
·30	44
·46	[illegible]
·04	63
·57	109
·25	123
·64	131
·50	125
·14	119
·80	138
43	120
55	95
56	100
86	83
60	100
96	111
88	99
34	133
09	76
34	142
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67	70
28	72
58	69
76	133
30	153
77	124
93	104
43	118
13	77
81	156
88	130
24	92
49	118
75	95
95	122
87	142
13	172
11	104
10	111
93	143
45	121
61	153